Clinical Research Report

Journal of INTERNATIONAL MEDICAL RESEARCH

Journal of International Medical Research
2019, Vol. 47(10) 4775–4786

DOI: 10.1177/0300060519865625
journals.sagepub.com/home/imr
SAGE

Double-pedicle propeller flap for reconstruction of the foot and ankle: anatomical study and clinical applications

Jianxiong Zheng[1,*], Hua Liao[2,*], Jie Li[1], Lingjian Zhuo[1], Gaohong Ren[1], Ping Zhang[1] and Jijie Hu[1]

Abstract

Objective: Reconstruction of soft tissue defects in the foot and ankle remains challenging. This study was performed to investigate the technical points and clinical effects of a double-pedicle propeller flap for repair of foot and ankle soft tissue defects.

Methods: We used five fresh calf specimens to investigate the anatomical and operative aspects of a double-pedicle propeller flap. Eighteen patients with soft tissue defects in the foot and ankle subsequently underwent defect repair with double-pedicle propeller flaps.

Results: The anatomical study showed that the peroneal artery perforators and the sural nerve bundle (two blood supply systems) provided the theoretical anatomical basis for the double-pedicle propeller flap. The relative positions of the peroneal artery perforators and the sural nerve bundle differ according to the peroneal artery perforating level. Flap rotation in different directions can reduce or prevent the pedicles from compressing each other. All flaps survived, and three flaps developed local epidermal necrosis at the proximal end; these flaps healed after 1 to 2 weeks of dressing changes. The other 15 patients healed well.

Conclusions: The double-pedicle propeller flap can enhance the blood supply and venous return in the "big paddle" region of the flap, reducing the distal necrosis rate.

[1]Department of Traumatic Orthopedics, Nanfang Hospital, Southern Medical University, Guangzhou, Guangdong, China
[2]Department of Human Anatomy, School of Basic Medical Sciences, Southern Medical University, Guangzhou, Guangdong, China

*These authors contributed equally to this work.

Corresponding author:
Jijie Hu, Department of Traumatic Orthopedics, Nanfang Hospital, Southern Medical University, No. 1838 Guangzhou Avenue North, Guangzhou 510515, China.
Email: jjh@smu.edu.cn

Keywords
Double-pedicle flap, peroneal artery perforator, sural nerve bundle, foot and ankle, propeller flap, necrosis

Date received: 1 April 2019; accepted: 3 July 2019

Introduction

Reconstruction of soft tissue defects in the ankle remains a challenging issue. Parts of the hindfoot, especially the tendons and heel, require flap coverage even for small soft tissue defects.[1] The sural artery flap and the peroneal artery perforator propeller flap are two commonly used local flaps for reconstruction of foot and ankle defects. However, their clinical application is often associated with complications. The two flaps are anatomically adjacent to each other, and although they have a cross-supply area, they belong to two different blood supply systems.[2] Our team envisaged that the two vascular pedicles should be included in the flap to provide a dual blood supply, which can achieve an effect similar to arteriovenous supercharging. This double-pedicle propeller flap technology can improve the blood supply and venous return of the distal flap, thereby reducing the partial necrosis rate of the distal flap while simultaneously retaining the inherent advantages of the local perforator flap.[3] Our research team designed and clinically applied a double-pedicle propeller flap and achieved good results. This study fills the current knowledge gap regarding the relative positional relationship between the peroneal artery perforators and the sural nerve bundle in the lower one-third of the calf and establishes the optimal rotational direction of the double-pedicle flap, which will be beneficial for surgeons to further utilize and expand the double-pedicle flap.

Materials and methods

Anatomical study

From November 2016 to May 2017, the research team dissected five fresh human calf specimens (specimens were provided by the Department of Anatomy, Southern Medical University). First, the skin and subcutaneous tissue were cut longitudinally along the posterior border of the fibula, and the perforating blood vessels of the peroneal artery were then identified and exposed. Second, the sural nerve bundle and small saphenous vein were identified. Third, we observed the anatomical relationship between the lower one-third of the peroneal artery perforator sites and the sural nerve bundle and explored the traffic branch vessel between the sural artery and the perforating branch of the peroneal artery. Fourth, we identified the axial line as the line connecting the midpoint of the popliteal fossa with the midpoint between the Achilles tendon and lateral malleolus. With the perforator of the peroneal artery as the rotation point, the sural nerve bundle was gradually separated from the foot to the rotation point. The double-pedicle propeller flap was designed with different perforators and different (left and right) lower limb specimens. The sural nerve bundle and the small saphenous vein were cut off on one side of the large paddle area of the flap. The small saphenous vein was cut off on one side of the small paddle area of the flap and was contained in the flap. After the flap was cut, the effects of

Figure 1. Anatomical diagram of the lower peroneal artery perforating branch and sural nerve bundle. At the 2.5-cm peroneal artery perforation level above the lateral malleolus, the sural nerve travels slightly anterior. At the 5- to 7-cm peroneal artery perforation level above the lateral malleolus, the perforator of the peroneal artery travels slightly anterior. The black arrow indicates the sacral vascular pedicle of the sural nerve. The red arrow indicates that the peroneal artery penetrates the vessel at 2.5 cm and 7 cm on the lateral malleolus. The blue arrow indicates the small saphenous vein.

different directions of rotation on the pedicle tension of the double pedicles were observed (Figure 1).

Patient study

All patients involved in this retrospective study were admitted to Nanfang Hospital from February 2018 to December 2018. All patients underwent surgery by the same surgeon. The inclusion criteria were a soft tissue defect of the foot and ankle measuring up to 15 cm (length) by 10 cm (width) and accompanied by exposure of tendons, blood vessels, nerves and bones, and a patient age of 5 to 65 years. The exclusion criteria were an age of <5 or >65 years, lateral and posterior injury of the lower leg, an unfinished treatment plan, and incomplete clinical data. The study protocol was approved by the Nanfang Hospital Ethics Committee (2018-12). All patients provided written informed consent for participation in the study and for publication of the images.

Surgical treatment

Preoperative treatment. All patients underwent debridement after admission. The wound was closed with a vacuum-assisted closure device that generated negative pressure, antibiotics were used to prevent infection, and the vacuum-assisted closure device was released after 3 to 5 days. When the wound was in good condition, the second stage of the flap operation was performed. If the wound condition was not good and purulent secretion still existed, debridement was continued. The vacuum-assisted closure device was replaced until the wound was in good condition, at which point the flap transfer was performed.

Flap design and operation (Figure 2). Preoperatively, a hand-held Doppler ultrasound detector was used to detect the perforating point of the peroneal artery, which was marked as the rotation point. The axial line is the line connecting the midpoint of the popliteal fossa with the midpoint between the Achilles tendon and lateral malleolus. Each flap was designed according to the size and shape of the defect area and the distance from the defect area to the rotation point. For each flap, the perforating vessel and the sural nerve bundle were located. The 2.5-cm or 5- to 7-cm perforator above the lateral malleolus was selected as the final rotation site, and the flap was taken as the center when adjusting the orientation of the flap. The adipose tissue around the perforator of the peroneal artery was carefully separated under a head-mounted magnifying glass, and the perforating vessels were exposed. The sural nerve bundle was separated subcutaneously from the distal end of the flap to the point of rotation. The sural nerve bundle was finally adjusted to the same horizontal plane of rotation or to 0.5 cm above the point of rotation. The proximal and distal saphenous veins were ligated and included in the flap. The flap was then cut through the superficial fascia

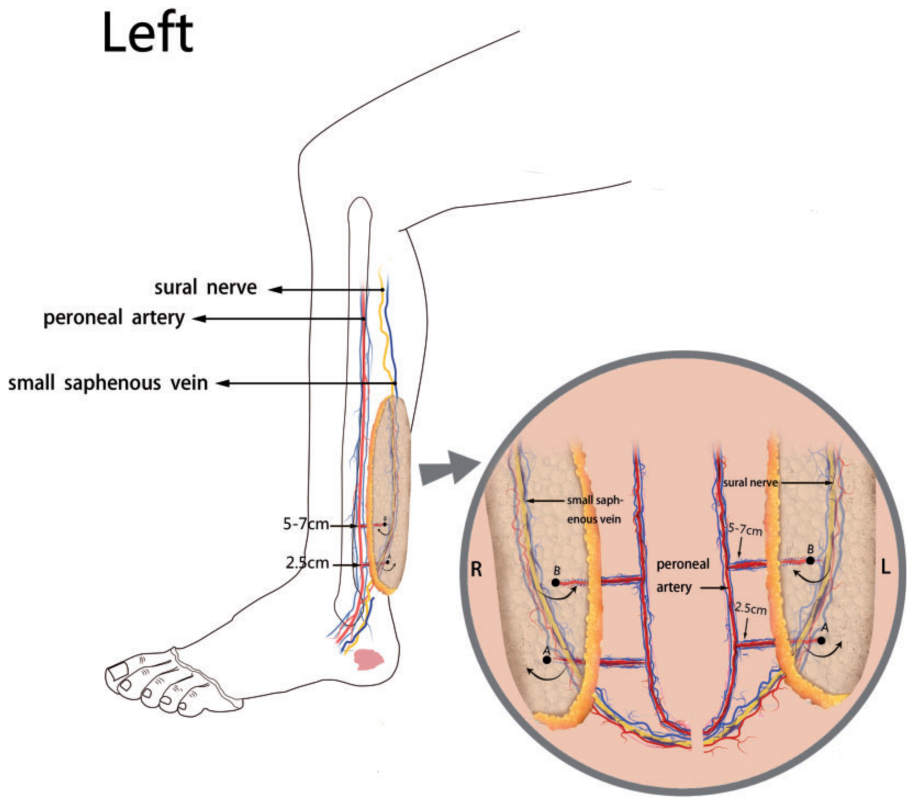

Figure 2. Schematic diagram of flap cutting and correct rotation direction. The two points A and B represent the 2.5-cm and 5- to 7-cm peroneal artery perforation above the lateral malleolus. The A and B points are the flap rotation center. The direction of the rotating arrow represents the correct direction of flap rotation. The left and right sides of the same peroneal artery-perforated horizontal flap rotate in opposite directions.

layer according to the design (retaining 0.5 cm of the superficial fascia around the sural nerve bundle), and the tourniquet was loosened to observe the blood supply around the flap. The double pedicles were rotated counterclockwise or clockwise to cover the defect.

Postoperative treatment and follow-up. Postoperatively, a short leg plaster was fixed to the functional position of the ankle joint, and the flap blood flow was observed every hour for 3 to 5 days. If surface blisters appeared or the flap swelled, the responsible suture was removed from the perforating vessel. We used mannitol for treatment at a dose of 125 mL twice a day with a small amount of dexamethasone. When venous congestion of the flap occurred, we used a heparin-soaked cotton ball to wipe the edge of the flap. The patients were followed up at 1 and 3 months after surgery. The patients' American Orthopedic Foot and Ankle Society (AOFAS) scores were recorded 3 months after surgery.

Results

The fresh specimen anatomy study revealed that two or three peroneal artery

Table 1. Relationship between the low perforators and the sural nerve bundle.

Patient no.	Total perforators	Perforator site 1	Compared with sural nerve bundle	Perforator site 2	Compared with sural nerve bundle	Perforator site 3	Compared with sural nerve bundle
1	2	2.5 cm	Posterior	7.0 cm	Anterior		
2	3	2.0 cm	Posterior	2.5 cm	Posterior	6.8 cm	Anterior
3	3	2.7 cm	Posterior	5.0 cm	Anterior	6.5 cm	Anterior
4	2	2.3 cm	Posterior	6.0 cm	Anterior		
5	2	2.5 cm	Posterior	6.5 cm	Anterior		

Perforator site: vertical distance between the perforator of the peroneal artery and the lateral malleolus.
Compared with sural nerve bundle: positional relationship of the perforator relative to the sural nerve bundle.

perforators were present approximately 7 cm above the lateral malleolus. The peroneal artery perforator was mainly located 2.5 cm and 5 to 7 cm above the lateral malleolus. The sural artery and vein were accompanied by the sural nerve and formed a sural nerve bundle. The relative positions of the peroneal artery perforators and the sural nerve bundle differed according to the peroneal artery perforation level. At the 2.5-cm peroneal artery perforation level above the lateral malleolus, the perforator site was posterior compared with the sural nerve bundle. At the 5- to 7-cm peroneal artery perforation level above the lateral malleolus, the perforator site was anterior compared with the sural nerve bundle (Table 1). The peroneal artery perforating vessels and the sural nerve bundle had a traffic branch that could be seen under a microscope. Two blood supply systems provide the theoretical anatomical basis for the double-pedicle propeller flap. Different planar double-pedicle propeller flaps can reduce only the compression of the double pedicles by rotating in different directions (Figure 3).

From February 2018 to December 2018, the research team recruited 18 patients with soft tissue defects of the foot and ankle for repair with double-pedicle propeller flaps. The patients comprised 13 males and 5 females ranging in age from 6 to 62 years (average age, 34.94 years). The soft tissue defects were caused by trauma in 11 patients, poor healing of incisions over the calcaneus in 3, osteomyelitis in 2, a chronic wound ulcer in 1, and melanoma in 1. The soft tissue defect was located on the foot in eight patients, the heel area in seven, and the malleolar area in three. Seven patients had a long history of smoking. The flap size ranged from 6×3 cm to 21×5 cm.

All flaps survived, and the distal end of the flap healed well (Figure 4). The two patients who presented with wound ulceration after calcaneal fracture had local superficial necrosis at the proximal end of the flap. The wound eventually healed after a dressing change (Figure 5). In the patient with melanoma of the foot and a long history of smoking, superficial necrosis appeared in the proximal part of the flap after surgery and finally healed after dressing changes. After 3 months, the patients' AOFAS scores ranged from 82 to 98 points (average, 91 points). All patients with double-pedicle propeller flaps were satisfied with the shape of the flaps and met the functional walking requirements (Table 2).

Discussion

In recent years, sural artery flaps and peroneal perforator propeller flaps have been used to repair soft tissue defects of the foot and ankle.[4,5] In our past 8 years of research involving 35 cases of sural nerve

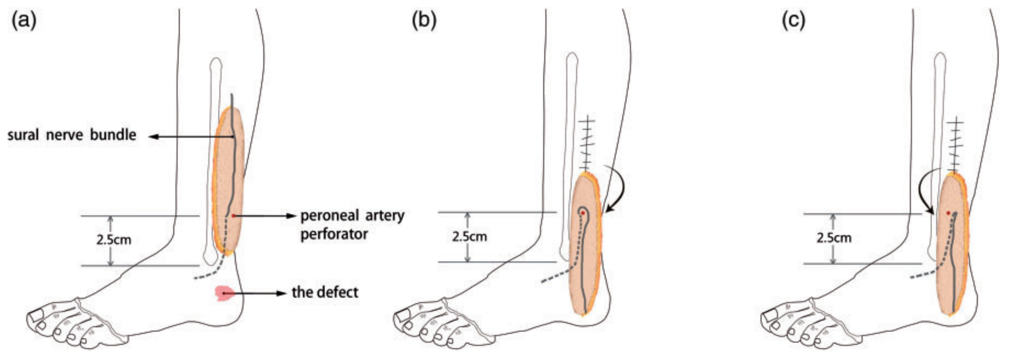

Figure 3. Diagram of different rotation directions of the 2.5-cm double-pedicle propeller flap above the left lateral malleolus. (a) The red point represents the 2.5-cm peroneal artery perforator above the left lateral malleolus, and the sural nerve bundle is located in front of the perforator. The solid line represents the sural nerve bundle retained in the flap, and the dotted line represents the sural nerve bundle separated from the flap. (b) The flap is rotated 180 degrees clockwise. The sural nerve bundle is tightly wound around the peroneal artery perforator, and the flap is prone to vascular crisis. (c) The flap is rotated 180 degrees counterclockwise. The peroneal artery perforating vessels and sural nerve bundle can reduce compression, and the flap blood supply is not affected.

flaps and 21 cases of peroneal artery perforating vascular flaps, the rate of venous congestion and partial necrosis of the sural nerve artery flap was 28.57%, while that of the peroneal artery perforator flap was 23.81%. Venous congestion and partial necrosis are major problems associated with these two local flaps.

We believe that these two types of local flaps result in venous congestion and partial necrosis for the following three reasons. First, the venous wall of a single artery blood supply is thin, and the diameter of the tube is narrow. Thus, it is easy to shrink or even occlude the artery with external force, forming a thrombus, and the other superficial veins are destroyed, restricting the blood flow.[6] Second, the sural nerve fascia pedicle may be composed of more tissue, restricting its rotation. The pedicle is easily distorted and subjected to compression, which then affects venous return. The distal peroneal position of the calf is superficial, and the perforating vascular pedicle is usually short. After being rotated 180 degrees, it is easily distorted, leading to venous congestion and partial necrosis. Third, the flap area may be too large, and more than one blood supply is likely to cause venous congestion and partial necrosis. Although many scholars[2,7–9] have studied the maximum safe access area for the sural artery flap and the peroneal artery perforated propeller flap, the safe cutting range of such flaps should be assessed. However, distal necrosis of the flap is still difficult to avoid in the clinical setting. Therefore, modifications of the traditional single-perforator propeller flap are necessary to solve this problem.

Multiple blood supply technology has been applied to calf flaps. In recent years, many scholars[10–12] have used the venous supercharging technique to design the sural artery flap and the peroneal artery perforator flap. By using the anastomosed superficial vein to increase the venous return pathway and thus reduce the congestion of the distal flap, this method can increase the blood circulation in the flap to a certain extent but cannot fundamentally solve the problem of insufficient blood supply. Bhatt et al.[13] designed reverse peroneal artery flap. This flap design includes

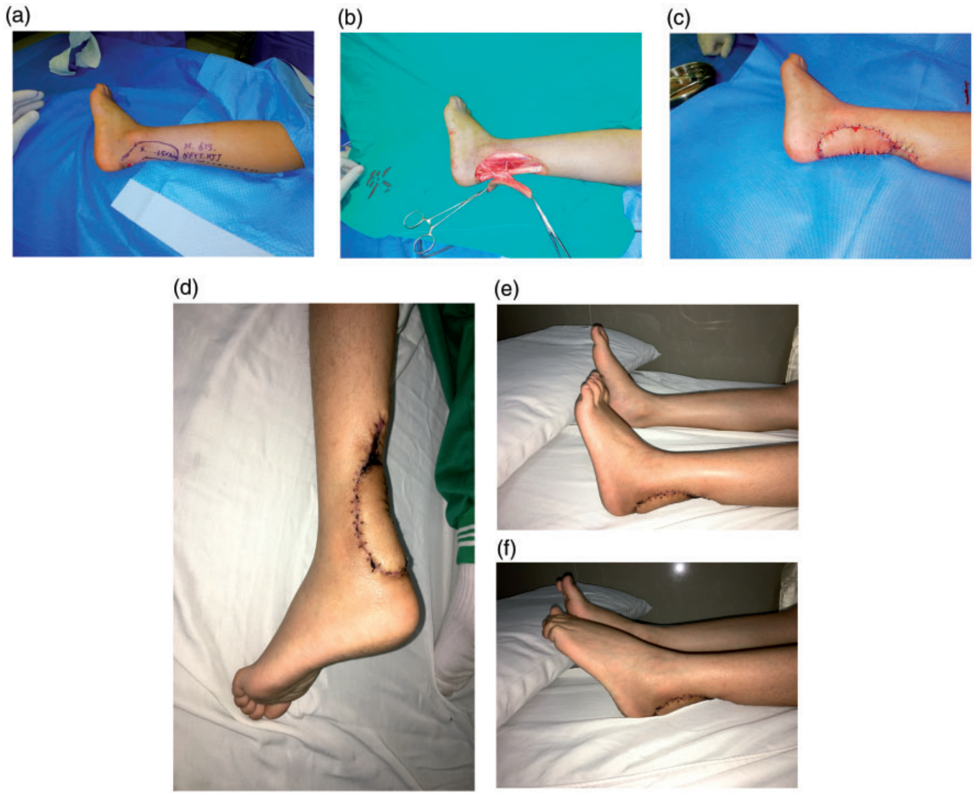

Figure 4. Patient 1. (a) A 6-year-old boy was admitted to the hospital because of ulceration of a left heel wound after a motorcycle wheel injury. The size of the left heel wound was 3×2 cm after intraoperative debridement, and the flap was designed according to the size of the wound. (b) The double-pedicle propeller flap was resected at a rotation site of 2.5 cm above the lateral malleolus, and the flap size was about 6×3 cm. (c) The flap was rotated 180 degrees counterclockwise to cover the wound. (d) The flap had healed well at 3 weeks after surgery, and the appearance was satisfactory. (e) Comparison of the affected side and the healthy side of the extended ankle joint 1 month after the operation. (f) Comparison of the affected side and the healthy side of the flexed ankle joint 1 month after the operation.

the reverse-flow peroneal artery along with the reverse sural system to achieve more distal and more reliable coverage. All 18 large-area flaps in the present study survived without venous congestion or partial necrosis. The dual vascular system provides a reliable blood supply to large flaps while protecting the blood vessels of the 5-cm traffic branch on the lateral malleolus. Anatomical separation of the area is not performed. The pedicle of the flap is more organized, relatively large, and easy to form into the shape of a cat's ears. Li Pandeng et al.[14] designed a double blood supply composite tissue flap with peroneal artery perforator and sural artery carrying gastrocnemius muscle in repairing lacunar skin and soft tissue defect of ankle. The pedicle of the island composite tissue flap contains peroneal artery perforator and sural artery to achieve double blood supply. The vascular pedicle of this group was located 5–15 cm above the lateral malleolus. The tissue flaps of 10 patients survived completely after operation at stage I. Follow-up for 1–12 months showed that

Figure 5. Patient 2. (a) A 33-year-old man was admitted to the hospital for ulceration of a left foot wound caused by a calcaneus fracture and osteomyelitis for 1 month. (b) The size of the left heel wound was 3×4 cm after intraoperative debridement, and the flap was designed according to the size of the wound. (c) The double-pedicle propeller flap was resected at a rotation site of 7 cm above the lateral malleolus, and the flap size was about 13×5 cm. (d) The flap was rotated 180 degrees clockwise to cover the wound. (e) The flap had survived well 1 month after surgery, but the proximal flap showed an area of superficial necrosis of approximately 3×3 cm. (f) The patient healed well and was able to stand up and walk 3 months after surgery. (g) Preoperative X-ray film. (h) Two-month postoperative X-ray film.

Table 2. Demographic data of the patients.

Patient no.	Sex	Age (years)	Etiology	Position	Flap size (cm)	Perforator site (cm)	Postoperative complications	Donor site closure method	AOFAS score (3 months after surgery)
1	Male	8	Trauma	Heel	8 × 3	3.0	None	Direct suturing	91
2	Male	33	Osteomyelitis	Foot	16 × 5	7.0	Proximal superficial necrosis	Direct suturing	82
3	Female	56	Chronic ulcer	Heel	10 × 3.5	5.0	None	Direct suturing	86
4	Male	6	Trauma	Heel	6 × 3	3.0	None	Direct suturing	98
5	Male	49	Postoperative complications	Foot	12 × 3	5.0	Proximal superficial necrosis	Direct suturing	92
6	Male	35	Trauma	Lateral malleolus	15.5 × 4	5.0	None	Direct suturing	94
7	Female	41	Trauma	Foot	17 × 5	5.5	None	Skin grafting	88
8	Male	6	Trauma	Heel	8 × 3	2.5	None	Direct suturing	94
9	Male	50	Trauma	Lateral malleolus	12 × 4	5.0	None	Direct suturing	90
10	Male	11	Trauma	Heel	7 × 3	2.5	None	Direct suturing	87
11	Female	49	Postoperative complications	Foot	16.5 × 4	5.0	None	Direct suturing	90
12	Male	62	melanoma	Foot	21 × 5	7.0	Proximal superficial necrosis	Direct suturing	96
13	Female	44	Trauma	Lateral malleolus	16 × 3	7.0	None	Direct suturing	96
14	Male	10	Trauma	Heel	7 × 3	2.5	None	Direct suturing	98
15	Male	32	Trauma	Foot	19 × 5	5.5	None	Skin grafting	88
16	Male	42	Osteomyelitis	Foot	18 × 4	6.0	None	Direct suturing	86
17	Male	40	Trauma	Heel	15 × 3.5	5.0	None	Direct suturing	92
18	Female	55	Postoperative complications	Foot	17 × 4	6.5	None	Direct suturing	90

AOFAS, American Orthopedic Foot and Ankle Society.
Perforator site: vertical distance between the perforator of the peroneal artery and the lateral malleolus.

the area repaired with tissue flaps had good appearance, and recovered different degrees of pain sensation and deep tactile sensation, and no short-term or long-term complications occurred.

Based on the existing literature, our research team designed a double-pedicle propeller flap. The distal end of the flap contains both the sural neurovascular network and the peroneal artery perforating vascular system. These branches of the flap together form a longitudinal chained vascular network. No venous congestion or partial necrosis occurred at the distal end of the double-pedicle propeller flaps in all 18 patients, and all flaps survived.

The following two points should be considered when performing surgical repair of a soft tissue defect with a double-pedicle propeller flap. First, accurate separation of the double pedicle vessels is critical. In particular, the "small paddle" is longer and the time and difficulty involved in separating the sural nerve bundle are greater. Among our 18 patients, we used a 2.5-cm or 5- to 7-cm perforator above the lateral malleolus (lower rotation point) to minimize the length of the sural nerve bundle in the "small paddle." During the separation process, the vessels of the sural nerve bundle and the superficial fascia may be damaged, resulting in local congestion of the small paddles. Care needs to be taken when separating the sural nerve bundle. To reduce vascular tension after rotation, the sural nerve pedicle is further separated from the proximal end of the rotation point by 0.5 to 1 cm if necessary. Second, the propeller must be rotated in the correct direction to reduce the risk of twisting the double pedicles. In our clinical and anatomical studies, we found that the direction of flap rotation can be affected by whether the foot being repaired is the left or right foot and by different peroneal artery perforation sites. In the anatomical study,[15,16] the perforating branch of the peroneal artery was distributed along the posterior border of the fibula, and the sural nerve bundle travelled along the midpoint of the lateral malleolus and the Achilles tendon to the midpoint of the popliteal fossa. We found that the relative positions of the peroneal artery perforators and the sural nerve bundle differ according to the peroneal artery perforating level. At the 2.5-cm peroneal artery perforation level above the lateral malleolus, the sural nerve bundle travels slightly anterior, so the 2.5-cm perforator above the lateral malleolus is slightly posterior. At the 5- to 7-cm peroneal artery perforation level above the lateral malleolus, the perforator of the peroneal artery is relatively anterior, and the sural nerve bundle is relatively backward. Based on these anatomical features, when we need to use the double-pedicle propeller flaps with a 2.5-cm perforator above the left lateral malleolus (to reduce the compression and vascular tension of the double pedicles), the flap must be rotated counterclockwise. If the 5- to 7-cm perforator above the left lateral malleolus is used, the flap should be rotated clockwise. When the 2.5-cm perforator above the right lateral malleolus is used, the flap needs to be rotated clockwise. If the 5- to 7-cm perforator above the right lateral malleolus is used, the flap needs to be rotate counterclockwise (Figure 2).

Perhaps in a larger-sample anatomical study, the relative position of the sural nerve bundle and the perforator of the peroneal artery may show variation. The optimal rotation direction of the flap can be adjusted accordingly. The ultimate goal is to reduce or avoid squeezing the double pedicles.

We believe that the double-pedicle propeller flap has the following advantages over other similar flaps. First, the flap contains two sets of arterial blood supply systems and two sets of venous return systems. There is no need to anastomose the blood vessels to generate a double blood supply and reflux. Furthermore, the operation is convenient, and the distal end of the flap is less prone to congestion or necrosis. Second, the flap can be rotated 180 degrees or even more around the center of the pedicle. Third, the "small paddle" can cover the donor area, unlike with other double-pedicle flaps; this can reduce the need for skin grafts.

In our group of patients, local superficial necrosis occurred in the proximal "small paddle" of the propeller flap after surgery and finally healed after dressing changes (Figure 5). One patient had a wound area of approximately 3×3 cm, another patient had an area of approximately 2×2 cm, and the third patient had an area of approximately 3×1.5 cm. We believe that this necrosis may have occurred for two reasons. First, the "small paddle" is adjacent to the soft tissue defect site, and local chronic inflammation may destroy the soft tissue blood supply in the region. Second, the sural nerve bundle needs to be separated from the distal end of the flap to the center of rotation, which may destroy the vascular network in the area of the small paddle. Third, smoking is another important factor affecting flap healing. For these reasons, we believe that separation of the sural nerve bundle and the small saphenous vein in the small paddle should be performed under a microscope to minimize the damage to the blood supply. Additionally, the length of the "small paddle" should not exceed 5 cm to avoid the possibility of congestion and necrosis at the proximal end after the flap is rotated.

Other problems associated with this type of flap are that the double-pedicle rotation still carries a certain risk of entanglement and compression and that the flap sacrifices the saphenous vein and sural nerve.

This study has a few limitations. Use of the double-pedicle propeller flap is rare in anatomical and clinical studies, and long-term follow-up data are lacking. It is also necessary to clinically verify the soft tissue defects of the forefoot and a larger area of the hindfoot.

Conclusions

The double-pedicle propeller flap can enhance the blood supply and venous return of the "big paddle" region in the flap. According to our current clinical experience, this type of flap appears to be able to better solve the problem of necrosis of the distal part of the flap compared with the original propeller flap. Thus, clinical application of the double-pedicle propeller flap is promising.

Acknowledgements

We would like to thank Southern Medical University and Southern Hospital. Southern Medical University provided the specimens for us, and Southern Hospital provided the funding for the project.

Declaration of conflicting interest

The authors declare that there is no conflict of interest.

Funding

This work was supported by the Southern Hospital Director Foundation (2015B002 and 2018B011).

ORCID iD

Jijie Hu https://orcid.org/0000-0002-7869-2911

References

1. Hollenbeck ST, Woo S, Komatsu I, et al. Longitudinal outcomes and application of the subunit principle to 165 foot and ankle free tissue transfers. *Plast Reconstr Surg* 2010; 125: 924–934.
2. Sur YJ, Morsy M, Mohan AT, et al. Three-dimensional computed tomographic angiography study of the interperforator

flow of the lower leg. *Plast Reconstr Surg* 2016; 137: 1615–1628.
3. Georgescu AV. Propeller perforator flaps in distal lower leg: evolution and clinical applications. *Arch Plast Surg* 2012; 39: 94–105.
4. Finkemeier CG and Neiman R. Reverse sural artery pedicle flap. *J Orthop Trauma* 2016; 30: 41–42.
5. Ahn DK, Lew DH, Roh TS, et al. Reconstruction of ankle and heel defects with peroneal artery perforator-based pedicled flaps. *Arch Plast Surg* 2015; 42: 619–625.
6. Chang SM, Wang X, Huang YG, et al. Distally based perforator propeller sural flap for foot and ankle reconstruction: a modified flap dissection technique. *Ann Plast Surg* 2014; 72: 340–345.
7. Wei JW, Dong ZG, Ni JD, et al. Influence of flap factors on partial necrosis of reverse sural artery flap: a study of 179 consecutive flaps. *J Trauma Acute Care Surg* 2012; 72: 744–750.
8. Panse NS, Bhatt YC and Tandale MS. What is safe limit of the perforator flap in lower extremity reconstruction? Do we have answers yet? *Plast Surg Int* 2011; 2011: 349357.
9. Gir P, Cheng A, Oni G, et al. Pedicled-perforator (propeller) flaps in lower extremity defects: a systematic review. *J Reconstr Microsurg* 2012; 28: 595–601.
10. Shen L, Liu Y, Zhang C, et al. Peroneal perforator pedicle propeller flap for lower leg soft tissue defect reconstruction: clinical applications and treatment of venous congestion. *J Int Med Res* 2017; 45: 1074–1089.
11. Li T, Chen Z, Cong X, et al. Clinical application of perforator propeller flaps with anastomosis of superficial veins. *Zhonghua Zheng Xing Wai Ke Za Zhi* 2015; 31: 107–110.
12. Dragu A, Bach AD, Kneser U, et al. Two easy and simple modifications when using a distally based sural flap to reduce the risk of venous congestion. *Plast Reconstr Surg* 2008; 122: 683–684; author reply 684.
13. Bhatt YC, Singh S, Doshi P, et al. Reverse peroneal artery flap for large heel and sole defects: a reliable coverage. *World J Plast Surg* 2017; 6: 212–219.
14. Li PD, Shen GL. [Clinical effect of double blood supply composite tissue flap with peroneal artery perforator and sural nerve nutrient vessel carrying gastrocnemius muscle in repairing lacunar defect of ankle]. *Zhonghua Shao Shang Za Zhi* 2019; 35: 392–394.
15. Kim H, Hu J, Chang H, et al. Sural nerve splitting in reverse sural artery perforator flap: anatomical study in 40 cadaver legs. *Plast Reconstr Surg* 2017; 140: 1024–1032.
16. Iorio ML, Cheerharan M and Olding M. A systematic review and pooled analysis of peroneal artery perforators for fibula osteocutaneous and perforator flaps. *Plast Reconstr Surg* 2012; 130: 600–607.